NPOESS System Architecture

Frederick L. Ricker
Program Director, Northrop Grumman Space Technology

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is currently under development, through a contract issued by the US government's Integrated Program Office (IPO). This paper briefly describes the architecture for the system, and explains some of the trades that were made to arrive at a design that satisfies the important criteria of affordability, data quality, data latency, and system availability. This system provides environmental sensing data and information that is critical to the needs of many users in civil and military, scientific and operational communities. The system outputs will permit accurate forecasts, rapid planning of military campaigns, quick response to environmental threats in order to minimize impacts to local and national economies, and decisions on long-range policy relating to the global climate.

As a national program, the NPOESS team has many contributors. In addition to the government team (the IPO is comprised of representatives from the Department of Commerce, Department of Defense, and NASA), Northrop Grumman Space Technology is the prime contractor responsible for overall management, system engineering and integration, and space segment development; Raytheon Intelligence and Information Systems is the largest subcontractor responsible for development of the ground segments and system engineering and integration support to NGST. Other subcontractors provide the important space borne sensors and payloads, they are listed in Figure 2.

The NPOESS system is comprised of five segments: the Space Segment (SS), the Launch Support Segment (LSS), the Command, Control, and Communications Segment (C3S), the Interface Data Processing Segment (IDPS), and the Field Terminal Segment (FTS). Each of these segments is scaleable in size, and affords some measure of system flexibility. This top-level system architecture is shown in Figure 1. This architecture serves both the NPOESS mission, and the NPOESS Preparatory Project (NPP) mission. The NPP mission is the responsibility of NASA Goddard Space Flight Center. The NPP mission serves two purposes: continuity of environmental data collection in the mid-morning polar orbit (following the NASA EOS Terra and Aqua deployments), and risk reduction for the future NPOESS mission. In the most basic terms, the system architecture provides the means to collect raw environmental data, convert that raw data into properly calibrated and validated attributes, which are provided to users as data records. The recipients of these data records are the four United States processing Centrals: Naval Oceanographic Office (NAVO), Fleet Numerical Meteorology and Oceanography Center (FNMOC), Air Force Weather Agency (AFWA), and National Environmental Satellite Data and Information Service (NESDIS).

The system architecture supports the straight-forward concept of operations. The system first senses the environmental phenomena aboard the spacecraft,

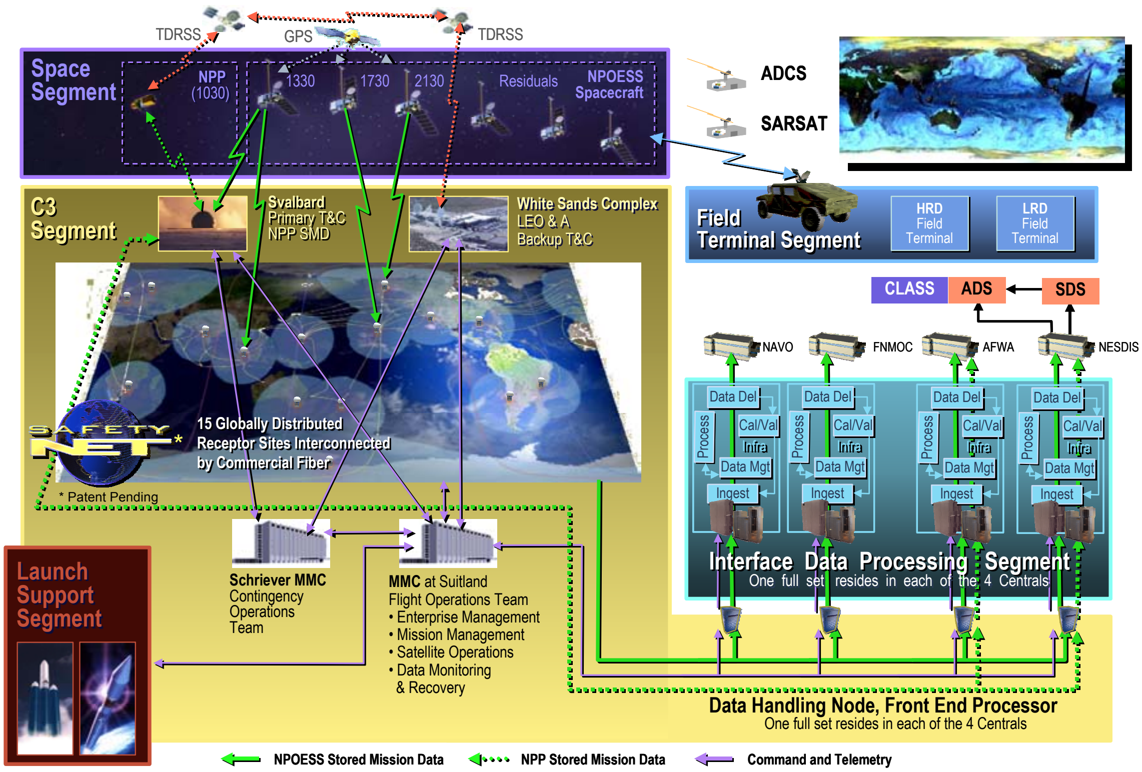


Figure 1. NPOESS System Architecture

the corresponding raw data output of the sensors and payloads are transmitted to the ground to awaiting field terminals, and to awaiting C3S receptors. The data received by field terminals are processed within these terminals. The data received by the C3S receptors are transported to each of the four Centrals for processing within IDPS, and then the data records are delivered to the users within the same Central facilities for further processing, distribution, and application. The data transport approach implemented by the C3S involves 15 globally distributed, unmanned, receptors, which are interconnected with IDPS by commercial fiber links. This network of receptors, and the detailed design for mission data transport are known to the program as Safety-Net, named to characterize the robustness afforded by this scheme. The entire system, space and ground, is monitored and controlled by the Mission Management Centers, at Suitland, MD or Schriever AFB at Colorado Springs.

The space segment is comprised of three spacecraft, each flying in a sun-synchronous polar orbit that is offset from the other by 4 hours. These orbits are often described by the local time their ascending node crosses the equator; so for NPOESS the orbits are: 1730 (also known as the early morning orbit because its descending node crossing time is 0530), 2130 (also known as the mid-morning orbit because its descending node crossing time is 0930), and 1330 (also known as the early afternoon orbit). By contractual definition, the NPOESS initial operational configuration is complete with two satellites, and its final operational configuration is complete with three satellites. The NPOESS contract includes options for the delivery of one additional backup for each orbit, so the full space segment includes six satellites. The satellite in each orbit carries a different complement of sensors and payloads. The spacecraft bus is the same for each orbital configuration, designed for "plug-and-play" interconnection with sensors. That way the spacecraft bus can accept any configuration of sensors prior to a short I&T period, before being delivered for launch. Furthermore, each spacecraft configuration has ample size, weight, power, and downlink data rate margins to permit the addition of Pre-Planned Product Improvement (P3I) sensors. This P3I capability permits system flexibility to accommodate mission evolution.

The space segment includes thirteen different types of sensors. These are described in Figure 2. This figure gives the names of the sensors, or payloads in the case of SARSAT and ADCS, the suppliers of the sensors or payloads, and a brief description of the heritage and status of these sensors or payloads. As explained above, a different selection of sensors and payloads is used in each of the three orbits. These configurations are described in Figure 3; a move of sensors between the 2130 and 1730 spacecraft is pending.

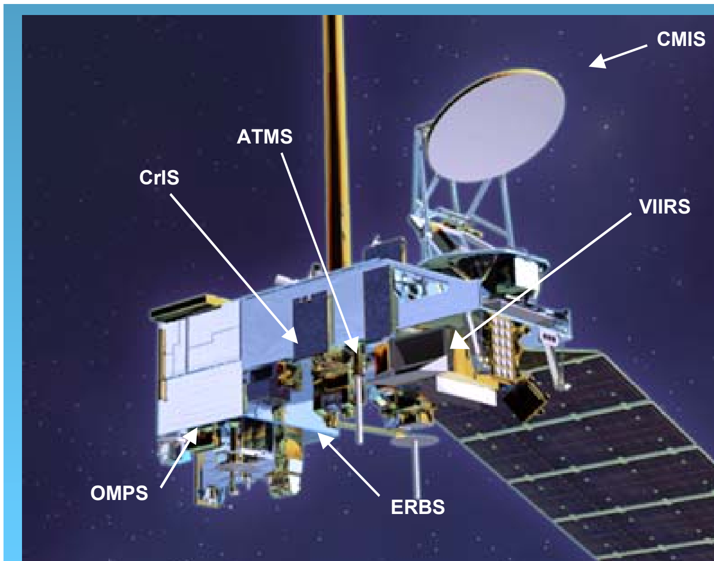
NPOESS Sensors		Sensor Supplier	Heritage/Status
Cross-track Infrared Sounder	CrIS	ITT	CDR August 2003
Visible/Infrared Imager Radiometer Suite	VIIRS	Raytheon SBRS	MODIS / CDR March '02
Advanced Technology Microwave Sounder	ATMS	Northrop Grumman Electronic Systems	AMSU / NPP unit being developed by NASA/GSFC
Conical Scanning Microwave Imager/Sounder	CMIS	Boeing Satellite Systems	SSM/I & TMI / CDR 11/05
Ozone Mapping and Profiler Suite	OMPS	Ball ATC	CDR March '03
Radar Altimeter	ALT	Alcatel (Fr.)	JASON & Topex-Poseidon
Earth Radiation Budget Suite	ERBS	NGST	CERES & ERBE
Total Solar Irradiance Sensor	TSIS	CU LASP	TIM & SIM / SORCE Jan '03
Space Environment Sensor Suite	SESS	Ball - Various	DMSP, POES, GOES
Advanced Data Collection System	ADCS	CNES (Fr.), NGST	GFE sensor, NGST antenna / POES
Search and Rescue Satellite Aided Tracking	SARSAT	CNES (Fr.), DND (Can.), NGST	GFE sensor, NGST antenna / POES
Aerosol Polarimetry Sensor	APS	Raytheon SBRS	NPOESS procurement delayed due to Replan and NASA GLORY Mission
Survivability Sensor	SS	NGST, Sandia	SSF DMSP

NPP Sensors include: VIIRS, CrIS, ATMS, OMPS

Figure 2. NPOESS sensors and payloads, 13 types

The sensors provide raw data that are used to create the output data records of NPOESS, which are provided to the users. The primary system output is Environmental Data Records (EDRs). A given sensor will produce data that may contribute to a number of EDRs. Also, the output of several sensors may be combined to produce a single EDR. A mapping of the sensors and EDRs is shown in Figure 4. This figure shows EDRs for both the NPP mission and the NPOESS mission. It also shows the EDR Key Performance Parameters (KPPs) which must be provided by each satellite. A satellite which fails to provide these KPPs may be replaced, in accordance with a government assessment and decision process.

The C3S is comprised of two Mission Management Centers, a primary Command and Telemetry ground station, a backup C&T capability, and the Safety-Net configuration of



NPOESS 1330 Configuration

	1330	1730	2130
VIIRS	X	X	X
CMIS	X	X	X
CrIS	X		X
ATMS	X		X
SESS	X		
OMPS	X		
ADCS	X	X	
SARSAT	X	X	X
ERBS	X		
SS	X	X	X
ALT		X	
TSIS		X	
APS			X

Figure 3. Sensors and Payloads for each NPOESS spacecraft configuration

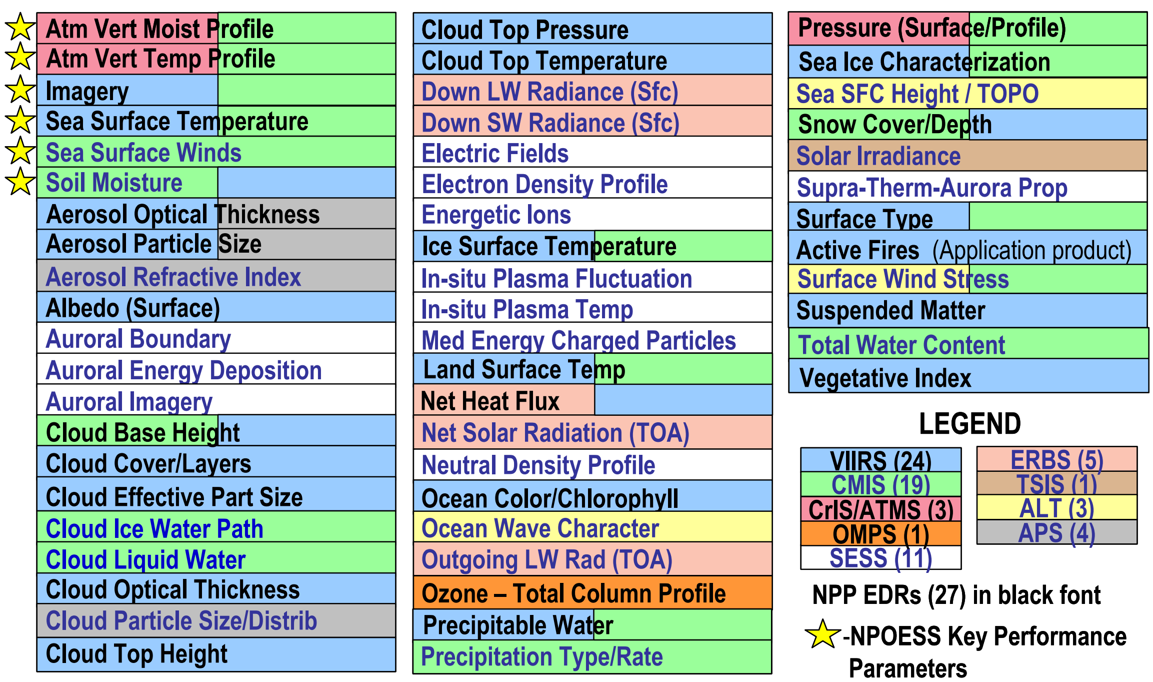


Figure 4. Mapping of Sensors and EDRs for NPOESS and NPP missions

ground receptors and commercial fiber links. The MMCs house the flight operations team. The C3S manages the operational system, performing the functions of: enterprise management, mission planning and resource scheduling, satellite operations, reception and accounting of mission data, anomaly resolution, system security, and delivery of data to and from central users.

The Interface Data Processing Segment is constructed with high speed, symmetric, multi-processing computers. The software within the IDPS is built upon algorithms that convert the raw sensor data from NPP and NPOESS space segments into the data records that are delivered to the four weather Centrals. The delivered data records include: Raw Data Records (RDRs), Sensor Data Records (SDRs), and Environmental Data Records (EDRs).

The Field Terminal Segment is a collection of fixed and mobile ground terminals deployed aboard ships, at military bases, in theaters of operation, and at educational and scientific institutions. Each field terminal receives broadcast signals from an overhead NPOESS satellite within its field of view, and performs data processing operations on this signal. Each NPOESS satellite continuously transmits signals at L-band (the Low Rate Data signal) and X-band (the High Rate Data signal). These signals are the real-time outputs of the on-board sensors, not the output of the Solid State Recorder (SSR). The FTS terminals will be equipped with specially configured IDPS software in order to perform the data processing operations.

Affordability continues to be a paramount consideration for the system. Cost trades are conducted routinely; to refine the "best value" solution as the design matures. In all cases, existing and proven technology is the basis of the system design. Several important trades were examined from a cost perspective, in the development of the system architecture. These are summarized below:

- A single spacecraft bus was more cost effective than unique spacecraft buses for the different sensor complements in each of the three orbits
- The use of Safety-Net for data transport was cost neutral when compared to using TDRSS as a means for data transport, yet Safety-Net provided assured data transport due to the dedicated nature of the system (the possibility of contention for a shared TDRSS is removed)
- The cost of providing an IDP capability at each Central was less than the cost of a single IDP with associated data routing to the other Centrals
- A high degree of automation is designed into C3S and IDPS for the purpose of lowering the Operations and Support costs
- The software development for IDPS produces "dual use" code, which can be readily installed on field terminal computers.

Data quality was also considered in the system architecture. Much care has gone into the derivation of sensor hardware performance requirements, sensor algorithm performance requirements, and system calibration/validation requirements. All of these combine to influence the system end-to-end performance relative to data products. An important aspect of system engineering for NPOESS includes the extensive modeling of sensors and their algorithms, for early checkout and verification of these algorithms before they are converted to operational software in the IDPS. Because some algorithms provide intermediate results that are used by other algorithms, these interactions are also modeled in the prediction of system performance.

Minimal data latency is an important characteristic of the system, since it reflects the speed by which raw data is ultimately converted and delivered to the user. Rapid delivery of data means that forecast warnings and now-casts are more timely. The system is designed to deliver more than 77% of the processed data within 15 minutes of observation, and more than 95% of the processed data within 28 minutes of observation. This compares very favorably to the data latency of current systems, which can be 4 times longer. The architectural feature that permits this latency capability is Safety-Net; because it enables high-speed communication from the spacecraft and ground receptors for more than 50% (average) of the orbit duration, as opposed to the current "store-and-dump" approach that schedules downlink transmittals once per orbit.

System availability has two aspects; data availability and operational availability. Data availability is defined to be the probability collected raw data is delivered to the user as a properly processed data record. In order for this probability to be high, the system is designed to provide the following:

- Solid state recorder (SSR) on the spacecraft capable of storing two orbits of all sensor raw output data (this is known as stored mission data, SMD)
- Duplicate transmittal of the SMD to two ground receptors
- Data storage of SMD at each ground receptor, to permit another retrieval if needed
- Data storage of SMD at the front end of each IDPS, to permit another retrieval if needed
- Data tracking algorithm at the MMC which accounts for data from the time it enters the spacecraft SSR until it is delivered to each Central; this permits another retrieval from any of the storage locations if data loss is detected along its path to the users.

The NPOESS is capable of achieving a data availability of greater than 99.95%. System operational availability is a measure of system "up time". In the case of NPOESS, the design includes some of the following features, which provide for high system availability:

- Hardware redundancy in the space borne sensors and payloads
- Hardware redundancy in the spacecraft subsystems (including the on-board data handling networks between the sensors and spacecraft SSR)
- Fault tolerant software in the sensors, spacecraft processors, and on-board data handling networks

- Hardware redundancy in the C3S receptors, data links, and MMCs
- Fault tolerant software within the C3S, to manage data flow upsets
- Hardware redundancy within the IDPS
- Fault tolerant software within the IDPS, to manage data processing and flow upsets.

Accounting for all the above redundancy and fault tolerance, the system operational availability for NPOESS is greater than 94.3%.

NPOESS capabilities will go beyond legacy systems to meet the complete set of military and civilian requirements. This is possible because of the application of exiting technologies for a cost-effective system; a comprehensive system engineering process to address data quality throughout the design and development activities; an innovative, global ground system that speeds data delivery for high performance data processing; and a flexible, scalable system architecture with ample redundancy and fault tolerance to ensure around-the-clock operations.